Construction of a Frequency Resolved Optical Gating (FROG) Diagnostic

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Many efforts in the area of single-shot, real-time recording of complex ultrafast waveforms (those with 100 fs to 1 ps detail and 100 ps to 1 ns record length) have no way of measuring the true response of the diagnostic systems because of difficulty independently characterizing the true input waveform. When no other measurement technique exists, it is difficult to know if details of the recorded waveform were real or artifacts of the recording instrument.

Frequency Resolved Optical Gating (FROG) is a well known and accepted "gold standard" technique for measuring such complex ultrafast waveforms. While a single-shot FROG system does not exist with the desired sensitivity and time-bandwidth product, a repetitively averaged, slow-scan system, could be constructed to measure these waveforms. This repetitively averaged measurement system would enable a more accurate characterization of the performance of the real-time recording systems in progress.

Project Goals

FROG is measurement technique that produces a frequency vs. time map of an optical signal in a manner similar to the way a musical score describes an acoustical signal. It does this by time-gating the optical field with a time-delayed replica of itself and recording the resulting output spectra vs. this delay. It is essentially a spectrally resolved autocorrelation. This analogy is shown in Fig. 1a, with Fig. 1b depicting one typical implementation in which the time gating is done through noncolinear second harmonic generation.

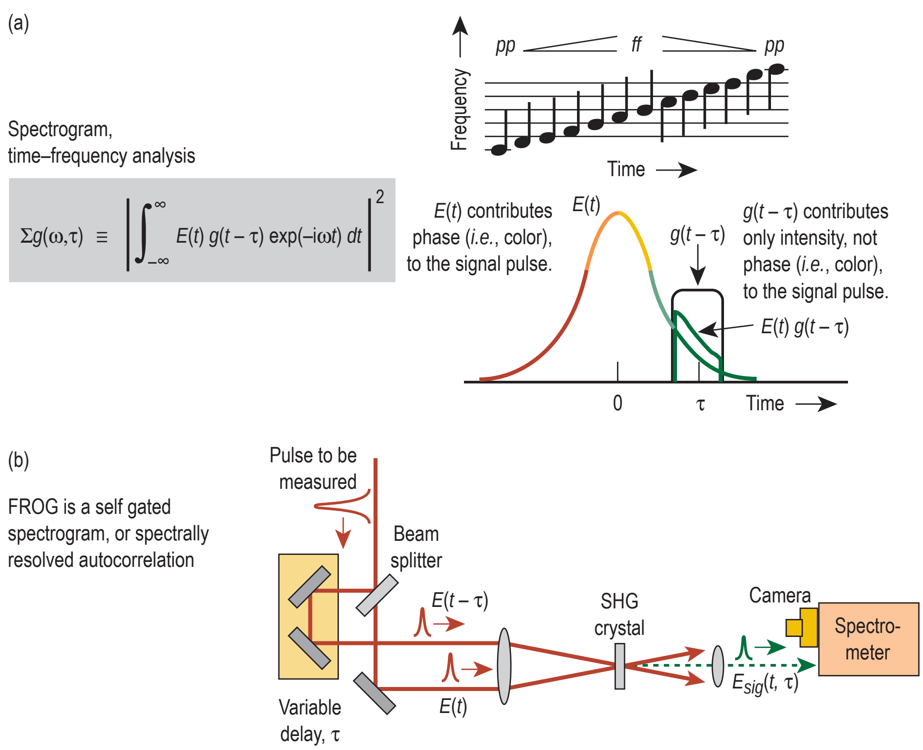

Figure 1. (a) Analogy between FROG and acoustic frequency analysis; (b) typical implementation in which the time gating is done through noncolinear second harmonic generation.

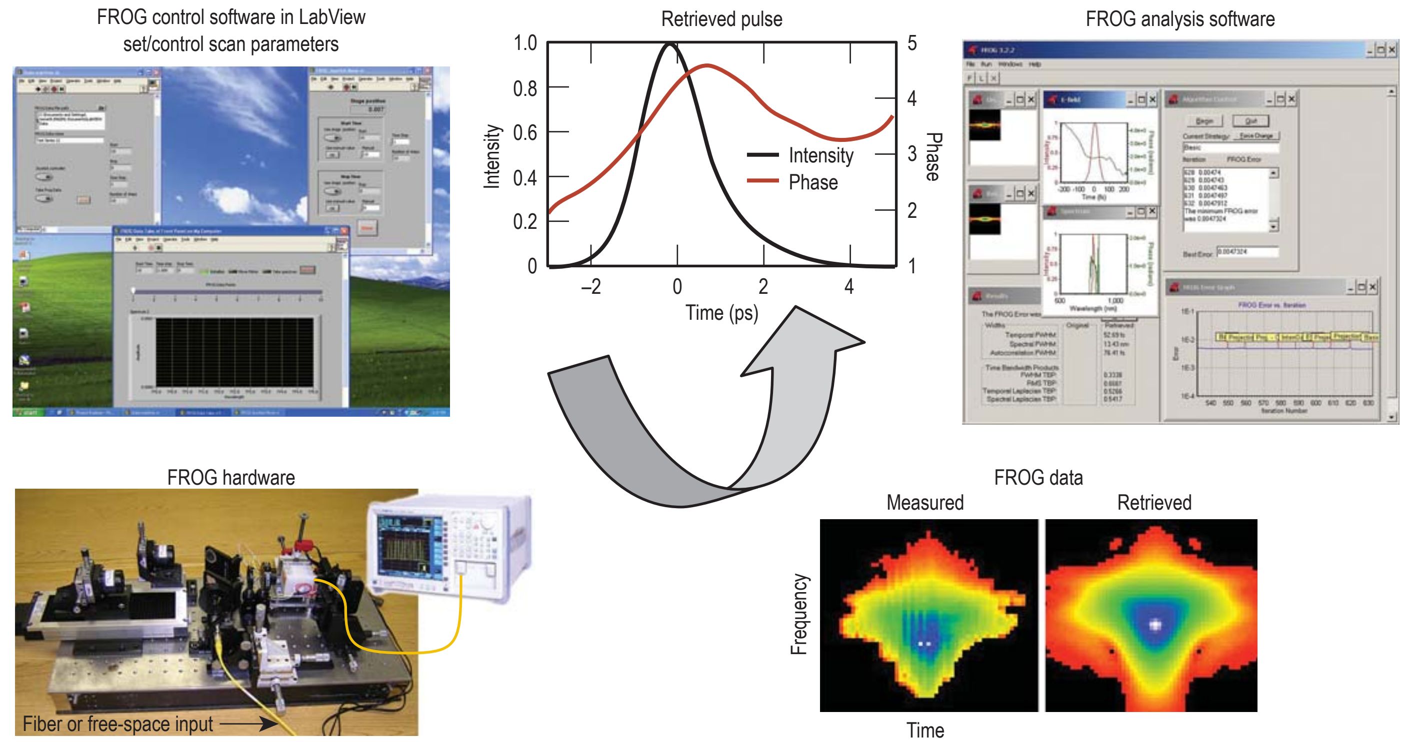

Figure 2. The FROG system. The process flow starts with the computer control windows in the upper left and flows in a counter-clockwise direction, resulting in the final pulse shape at the top. The actual hardware we constructed is shown in the lower left. The lower right shows a typical experimentally measured FROG trace along side a retrieved, or best matched, FROG trace obtained using retrieval software shown in the upper right. The desired information, the actual intensity and phase of the pulse vs. time is reported by the software and shown at the middle top of the figure.

The goal of this project was to build and test a FROG system with time-bandwidth product, and sensitivity necessary to measure ultrafast test signals in multiple projects within LLNL, *i.e.*, to add FROG to its measurement tool kit.

Typical signals have energies as low as 5 pJ/pulse, pulse durations from 100 fs to nearly 1 ns, time-bandwidth products up to 4000, and are approximately centered at a 1550-nm optical wavelength.

Relevance to LLNL Mission

Future high-energy-density science experiments at NIF and other facilities will require ultrafast real-time measurement systems with performance well beyond current technology, *i.e.*, ps and even faster temporal resolution with 10,000:1 dynamic range. There are also externally funded national security applications that require faster real-time diagnostics. What is needed is a 1-THz real-time oscilloscope, 50 times faster than the existing state of the art. Better tools, even if repetitively averaged, are required to aid in the creation and characterization of these new real-time recording instruments.

FY2007 Accomplishments and Results

We have successfully built and tested, and are in regular use of the FROG system shown in Fig. 2. One example of the accomplishments of this FROG system was the measurement of pulses matching in duration to within 1 ps, and frequency chirp (slope of the optical frequency vs. time) to within 2% of that reported by our temporal imaging-based diagnostic. The temporal imaging system makes a complete measurement on one pulse at a time and can repeat the measurement at 155 million measurements/s. The FROG system is an average of trillions of assumed to be identical pulses. The good agreement between these two different diagnostics gives us high confidence in the accuracy of the new temporal imaging technology.

Related References

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4. Trebino, R., K. W. DeLong, D. N. Fittinghoff, J. N. Sweetser, M. A. Krumbu, and B. A. Richman, "Measuring Ultrashort Laser Pulses in the Time-Frequency Domain Using Frequency-Resolved Optical Gating," *Rev. Sci. Instrum.*, **68**, 9, pp. 3277-3295, September 1997.

FY2008 Proposed Work

FROG will continue to be used as a tool in further work on SLIDER, ROPER, and the temporal imaging systems.